Convolutional neural network approach to event position reconstruction in DarkSide-50 experiment

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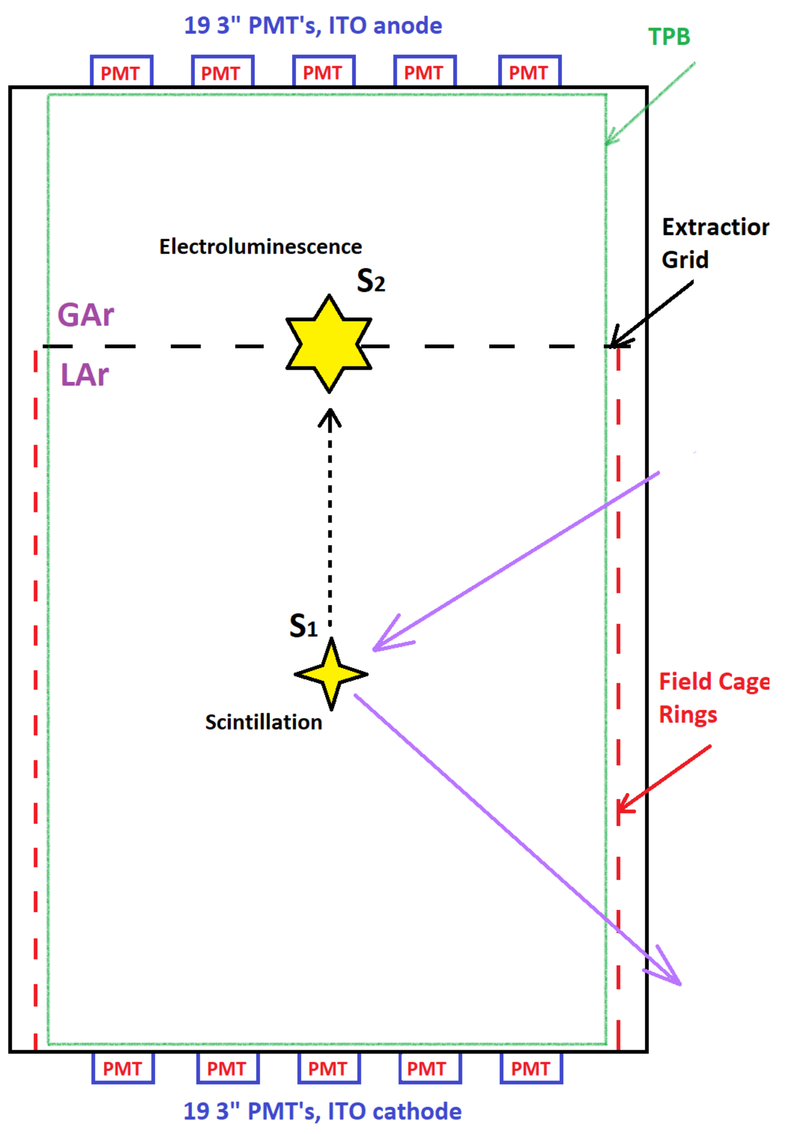
Abstract

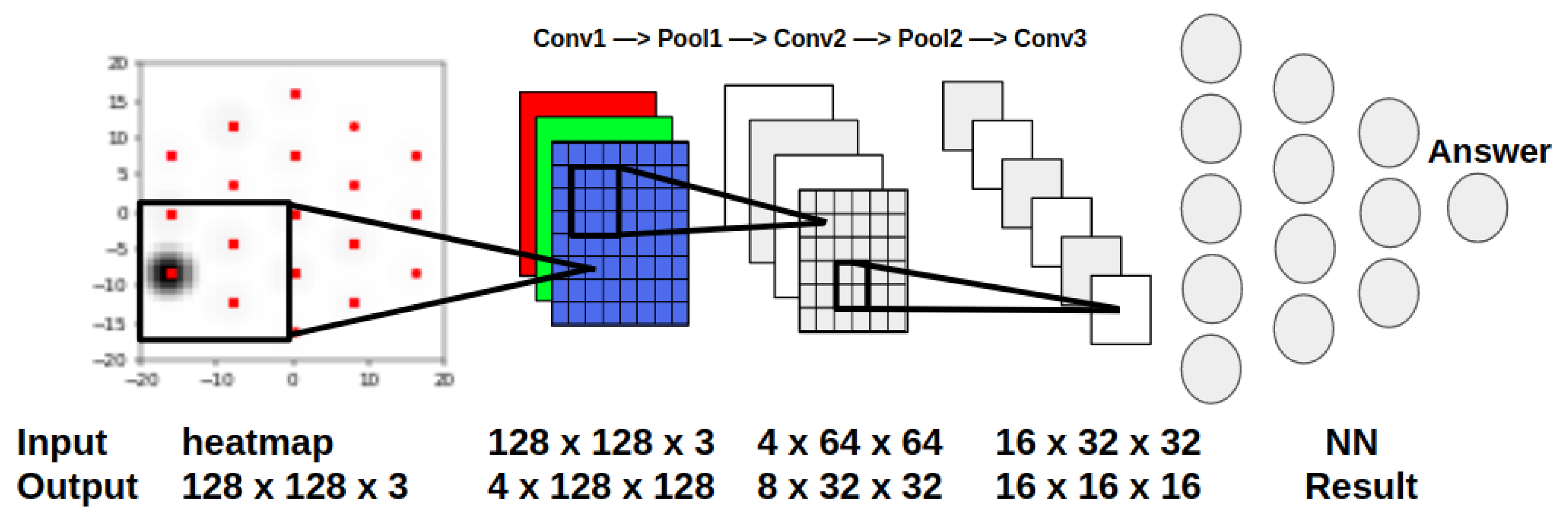
Neural networks are currently used in various fields of science, technology, as well as in experiments related to particle physics. DarkSide-50 is a two-phase (liquid and gas) argon TPC which has two main signals: scintillation in LAr and electroluminescence in GAr. Currently, only the more energetic second signal is used for position reconstruction. However, the used reconstruction method significantly reduces the fiducial volume of the detector. We use convolutional neural network (CNN) technique from Keras Python package to create new method of X-Y position reconstruction in DarkSide-50 experiment that will be equally effective and possibly outperform the existing one. We create a heatmap of each of the $15 \cdot 10^3$ Monte Carlo simulation events, divide them into the train and test samples, train our model and improve result by tuning model parameters.

Introduction to DarkSide-50 experiment

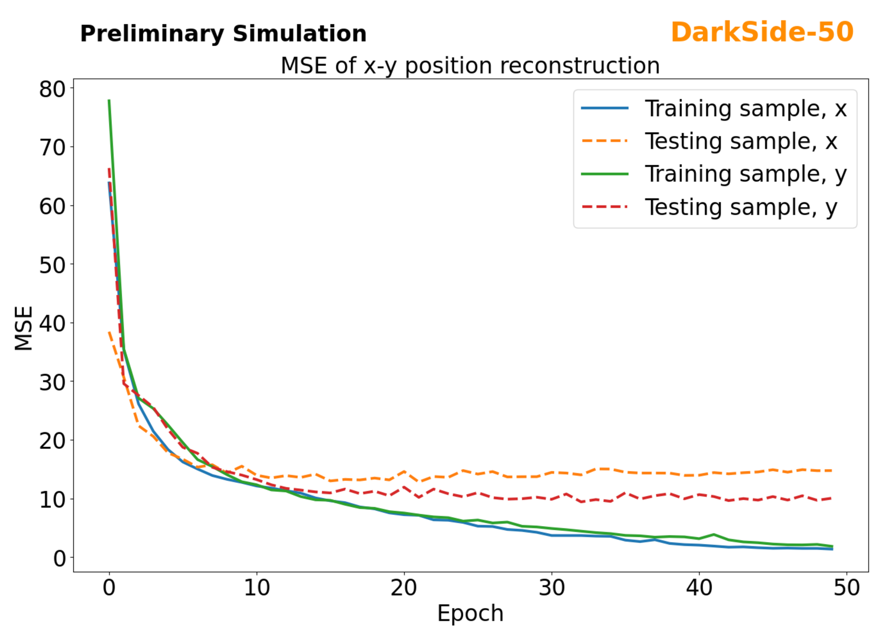


- 90% CL upper limit on the WIMP-nucleon spin-independent cross section of 6.1 $\times 10^{-44}$ cm^2 for a WIMP mass of 100 GeV/c^2;
- LNGS, Hall C at a depth of 3800 m.w.e.;
- (46.4 ± 0.7) kg. of LAr in the Time Projection Chamber(TPC);
- Gas layer between the LAr surface and the TPC anode;
- Viewed by 38 PhotoMultiplier Tubes(PMTs), 19 each on the top and the bottom.;
- It has wavelength shifter tetraphenyl butadiene (TPB), 128nm $\longrightarrow$ 420nm;
- Vertical electric field in LAr to make electrons drift up;
- PSD: detector can exploit $\frac{\text{scintillation}}{\text{ionization}}$ to reject β/γ background;
- Water Cherenkov Detector (shielding and muon detection): 11 m-diameter, 10 m-high cylindrical tank, high purity water, 80 8" PMTs on the side and bottom of the water tank;
- Liquid Scintillator Veto (neutron and γ-ray rejections): 4.0 m-diameter stainless steel sphere, 30 t of borated liquid scintillator, 110 8" PMTs.

CNN technique

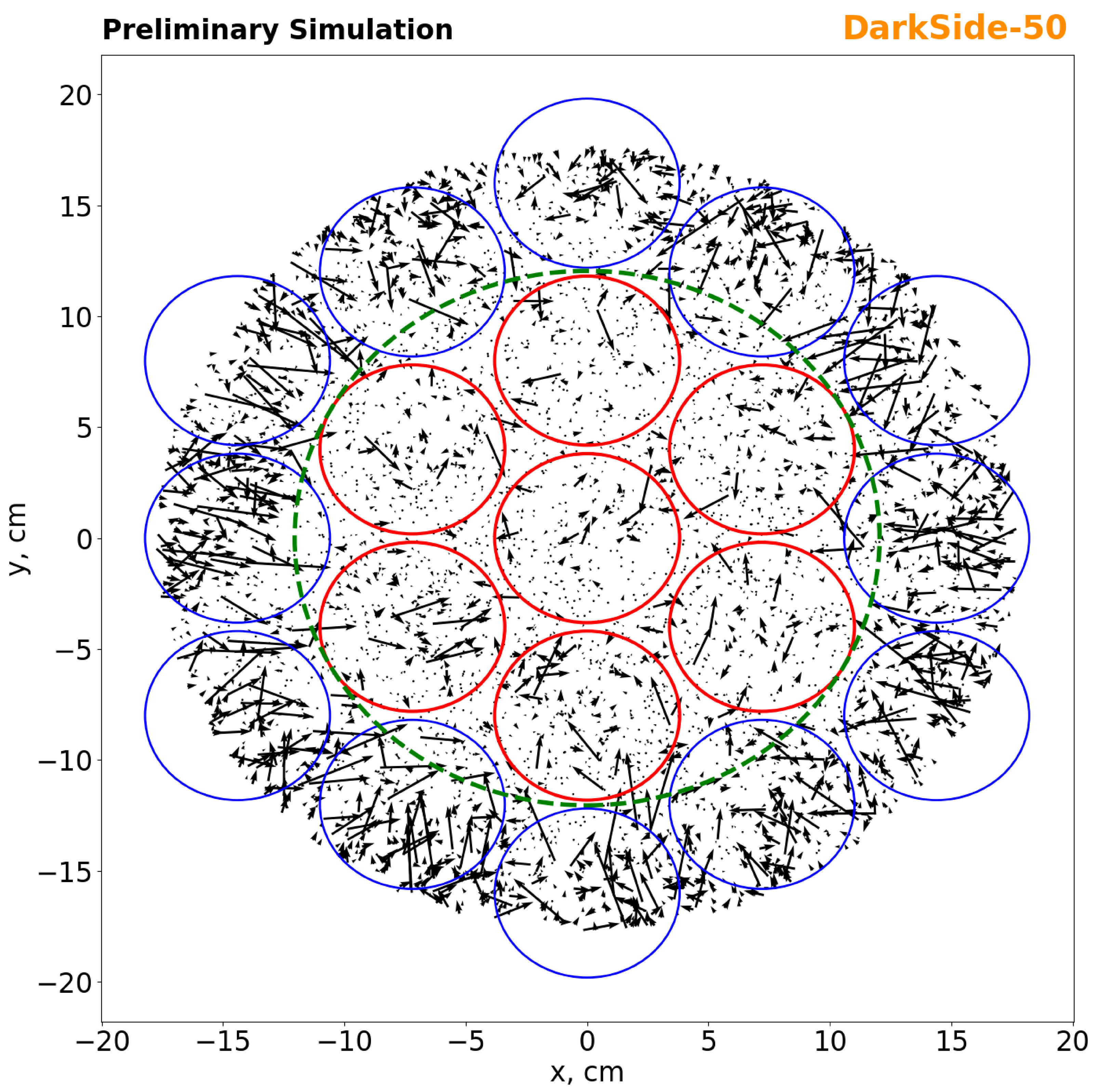


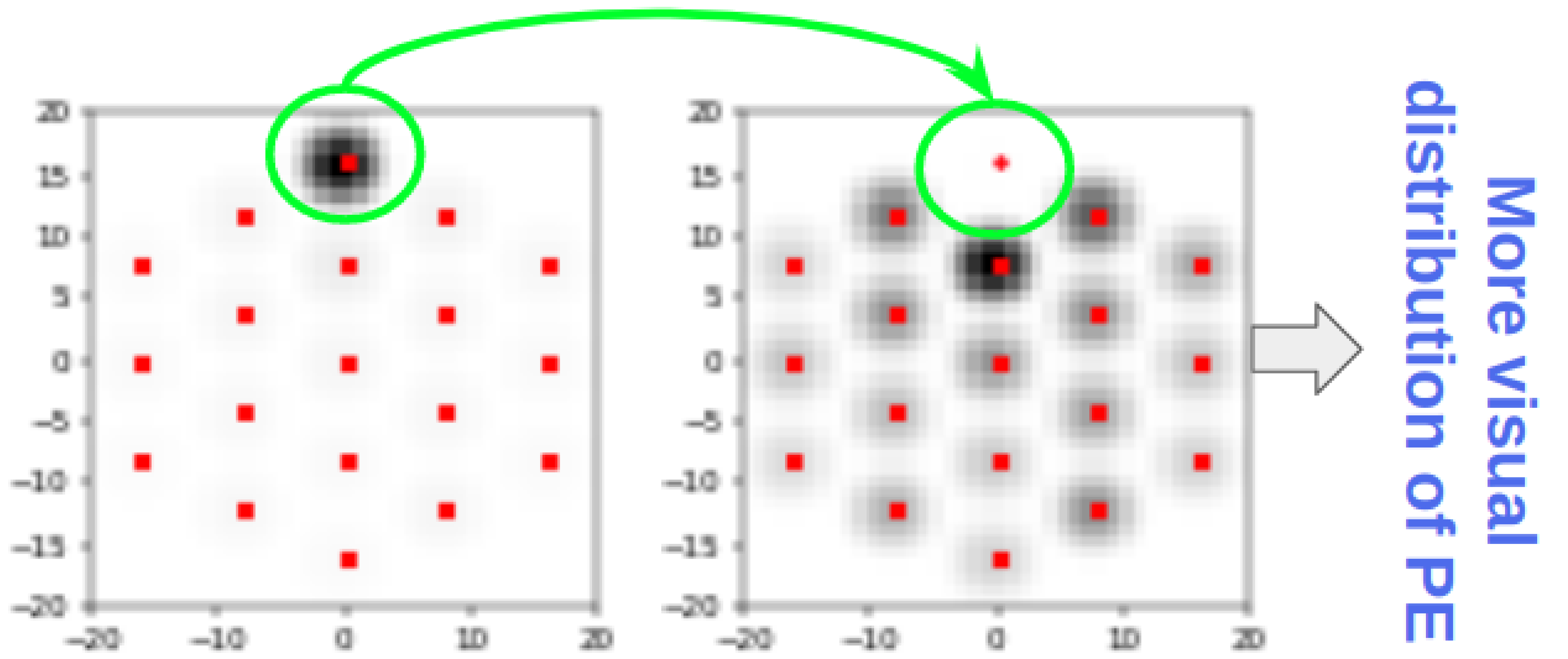
- **Heatmap** – 2D object that shows light pattern distribution in PMT's;
- **Convolution layer** – performs convolution of input layer with different kernels to detect leading features of the input;
- **Max pooling layer** – downsamples the input representation by taking the maximum value over the window defined by *pool size* for each dimension along the features axis;
- **Fully connected layer** – NN which take the results of the convolution/pooling and use linear transform and activation to predict X-Y coordinates.



- **Main goal** – is to achieve the minimum value of the mean squared error (MSE) parameter

Application CNN for event reconstruction





Top figure: Photoelectrons (PEs) distribution from S_2 signal in top 19 PMT's:
Left: original distribution;
Right: distribution in which the value of the PMT, which detected most PEs, is **set to one**.
Left figure: Plot, that shows reconstruction error: arrowtail and arrowhead correspond to the original and reconstructed position of the event:

- red circles correspond to 7 internal PMT's;
- green circle corresponds to the volume of the detector in which the error was calculated;
- Total MSE on **train sample** ≈ 4cm, total **validation** MSE ≈ 11cm for both **X and Y reconstruction**.

Summary

- Convolutional Neural Network **works and can** reconstruct X-Y position of events in DarkSide-50 experiment;
- **MSE** on **train sample** for 7 central PMT's ≈ 3 cm and 2.5 cm, **validation** MSE ≈ 4 cm and 3 cm for reconstruction of X and Y coordinates respectively;
- Next steps are: **increase** event statistic, **tune** CNN structure, **construct** new types of heatmaps.